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Marine Research
1958 No. 5

Herring (*Clupea harengus* L.) in Aquaria

I. Establishment

By B. B. PARRISH, B.Sc., J. H. S. BLAXTER, M.A.
and F. G. T. HOLLIDAY, B.Sc.

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE

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CONTENTS

	<i>Page</i>
INTRODUCTION	3
CAPTURE	4
TRANSPORT TO THE AQUARIUM	6
INITIAL ESTABLISHMENT IN THE AQUARIUM	6
Aquarium facilities	6
Initial mortality	7
Initiation of feeding	8
MAINTENANCE AND FEEDING AFTER ESTABLISHMENT	9
SUMMARY	10
REFERENCES	10
APPENDIX	11

Herring (*Clupea harengus* L.) in Aquaria

I. Establishment

INTRODUCTION

apart from investigations concerned directly with fish culture and rearing projects, the part played hitherto by aquarium studies in applied marine Fishery Research has been a relatively minor one. This is attributable principally to the fact that in the past marine fishery investigations have been concerned primarily with field surveys of the biological, ecological and dynamic properties of exploited fish species. However, as knowledge of such properties has accumulated, the demand has grown for more precise assessments of the factors governing them, and for greater accuracy in measuring them and understanding their basic mechanisms. There has thus arisen a need for experimental and observational studies, many of which cannot be obtained easily and without high cost at sea. Aquarium studies provide satisfactory means for supplying many of these data or for providing preliminary guides to the course along which subsequent field investigations should be directed.

The main types of projects which can be studied in aquaria, either completely or in part, can be divided for convenience into four major categories.

- 1) Basic physiology: e.g. studies of endocrine systems; food-growth relationships; osmotic relationships.
- 2) General behaviour patterns and responses to environmental stimuli: e.g. response to temperature, light and salinity gradients; shoaling, spawning and feeding habits.
- 3) Behaviour responses to artificial physical stimuli: e.g. behaviour to fishing gear components and model gears.
- 4) Dynamic properties of populations: e.g. predator-prey relationships; density dependent growth and mortality studies.

Each of these categories presents special problems of technique and makes special demands on the aquarium facilities. The most stringent demands are made perhaps by the last category for which balanced aquaria, containing large numbers of fish, are desired. For this reason, such projects are being tackled with populations of the smaller species of fish often kept by aquarists, rather than with species subject to commercial exploitation, for which the demands on space, etc. are too great for representative population characteristics to be reproduced in aquaria. While it may continue impracticable to investigate in these cases those mechanisms of population dynamics which demand controlled laboratory conditions for study, the difficulties are not so great for many of the projects in the first three categories. Worthwhile results and suggestions for future programmes of field observations can often be obtained with the species under investigation, using small numbers of fish in easily managed aquaria. It is these types of projects therefore which can be tackled most readily at fisheries laboratories. The programme of aquarium studies at the Marine Laboratory, Aberdeen, has been drawn up primarily for investigating projects in the first three categories, the principal species of fish at present under investigation being the herring (*Clupea harengus* L.). A brief list of previous experimental work on clupeoids is given in the appendix.

The first requirement in a programme of aquarium work is success in establishing the chosen species in the aquarium tanks. For some projects this may only involve keeping the fish alive for a few days, which may present no major difficulties, but for many others it involves establishing and maintaining self-sustaining feeding communities for long periods. It is this requirement which presents the greatest difficulty in many of the exploited species and which makes the most stringent demands on the general aquarium facilities.

Whether certain techniques are adequate or not for establishing fish will depend to a large extent on the species concerned. Thus the herring is a particularly delicate fish and the techniques used in establish-

ing it in aquaria must take this into account. It is by no means clear why one species should be delicate than another. In the herring the scales are easily displaced and the integument is thin and fragile. While this may be the prime reason, there may be some nervous factor operating which contributes to the general susceptibility of the fish. For instance, the herring is preyed on by many animals and thus its well developed behaviour in regard to escape from predators may make it particularly susceptible to shock during capture and handling. In this way it will become more agitated than many other species and may cause itself harm in trying to escape.

Success in the establishment of individuals of a species in an aquarium will be governed by a number of important factors operating at different stages in the establishment process. The main stages in the process are:

- (1) Capture
- (2) Transport to the aquarium
- (3) Initial establishment in the aquarium
- (4) Maintenance and feeding after establishment

In each of these stages factors affecting mortality and survival will operate and will govern the efficiency of the overall process. Furthermore, the factors operating in one stage may be the same as those operating in another stage or be closely linked with or dependent upon those operating in one or more of the other stages.

CAPTURE

This is undoubtedly the stage at which most damage may occur to the fish and for this reason the success or failure of an attempt to establish the fish in an aquarium often can be traced to this stage. The most obvious damage occurs to the epidermis and there may be considerable loss of scales. In addition there may be a shock effect, which will not be detectable physically, as well as other effects due to lack of oxygen and temperature and pressure changes. For these reasons the fish should be caught with a fishing gear which causes a minimum of physical damage. This is best accomplished by the use of a form of encircling net, e.g. purse or shore seine or pound or dip nets, where many of the fish make contact with the walls of the gear. Gears of this type have been used by a number of workers for capturing herring in good condition (e.g. Battle *et al* 1936, Cowan 1938, Verheijen 1953, 1956, Schäfer 1955, Farrin, Scattergood and Sindermann 1957). The most appropriate gear will depend on the habits of the fish but best results are likely to be obtained where the fish are within easy reach of the shore.

In our experiments most of the fish have been caught by beach seine at the mouth of the River Forth although trawls and drift nets have also been used. The herring caught by beach seine between 1957 and 1958 have been immature fish of three size groups, 0-group 8–15 cm long, 1-group 15–20 cm long and 2-group 20–25 cm long. The net is shot from a motor coble or rowing boat, the total time for hauling being about five minutes. When possible the net is kept in the water near the beach after hauling and the fish picked out by hand or by a fine net and put into containers. Most fish are caught at or near high water.

During 1953, 1955, 1956 and 1957 a total of six samples of adult fish were caught by drift net off the East Coast fishing grounds. On four occasions during 1957 1-group herring were caught with a 100 ft trawl in the Moray Firth and in 1958 ten hauls were made with a small ground trawl in or near Aberdeen Bay and large numbers of 0-group herring were caught. On one occasion in 1956 some 0-group (8–10 cm) were caught in Aberdeen harbour by means of a hand net.

A description of the mortalities resulting from different methods of capture will be given later, but it may be said that fish caught by beach seine have been established in aquaria with much greater success than those caught by other methods. It is possible, however, that this is not due only to the gear factors.

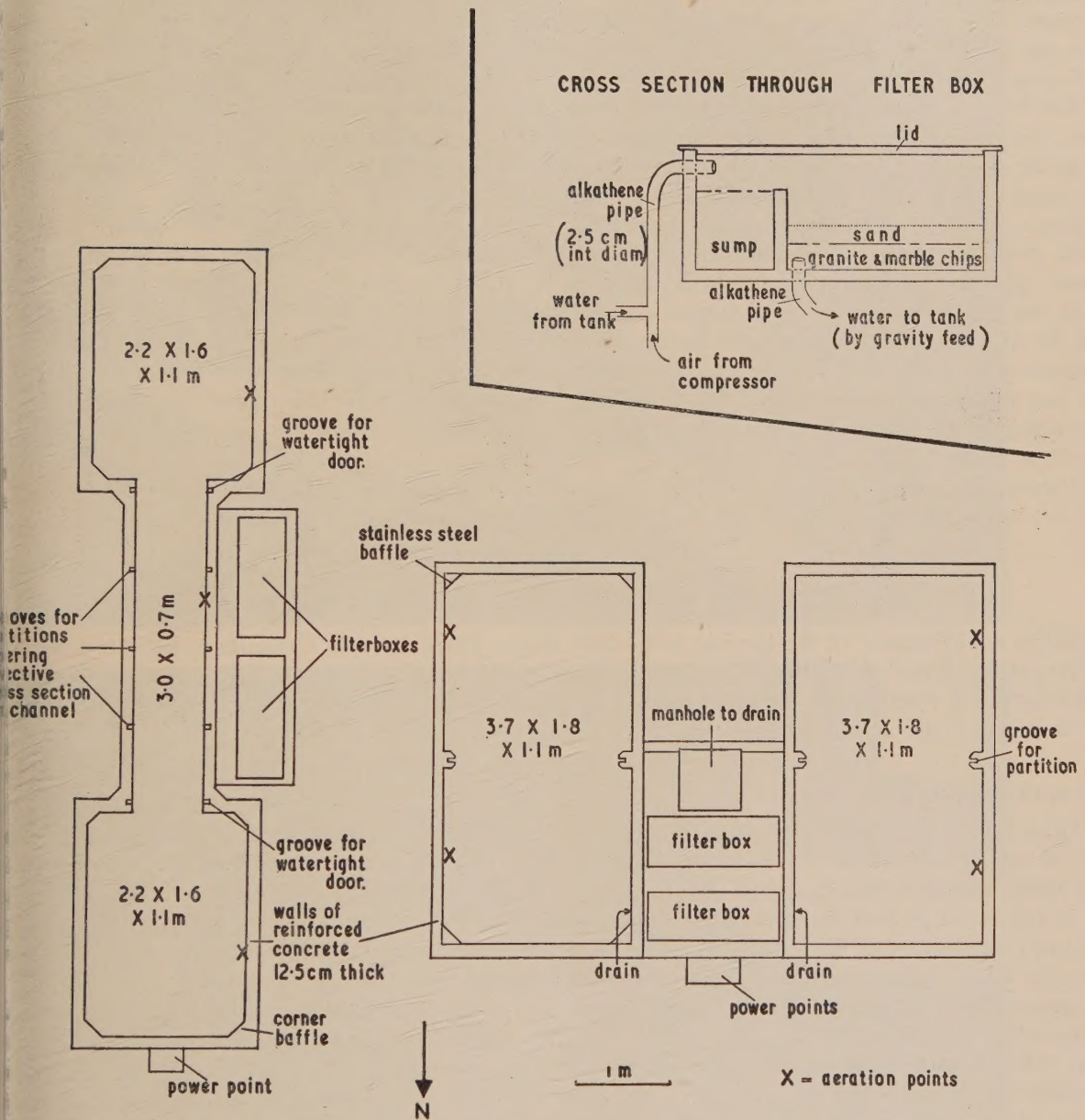


Fig. 1 Plan view of the tanks.

TRANSPORT TO THE AQUARIUM

The transport of the live fish from the point of capture to the aquarium constitutes the most important stage of the process of establishment. Satisfactory transport facilities are essential, particularly when the fish have to be transported long distances by road, rail or sea.

Receptacles for transporting fish should be adequate in size, both from the point of view of the fish room to swim and to ensure an adequate oxygen supply. A circular container permits the fish to swim continuously and fairly small containers can be used if an oxygen supply is available. The container should be smooth to prevent abrasion and the container should be nearly or completely filled with water and fitted with a lid to prevent splashing.

Battle *et al* (1936) used galvanised iron tubs. Verheijen (1953, 1956) used 60 l glass bottles. Farrin *et al* (1957) used steel milk cans holding 45 l with one 0-group fish per 1-2 l. Much larger containers (450 l) were used by Loukashkin and Groody (1955) for transporting sardines.

In our experiments bins, or carboys with wide mouths (13 cm across), holding about 50 l have been used for transporting fish from the beach or research vessels to the aquarium. While this has been satisfactory for short journeys lasting a few minutes, on longer journeys the same receptacles have been used but the water has been oxygenated and rail journeys of up to 60 miles have been made. To avoid overcrowding not more than one 0-group fish per 2-3 l or one 1-group fish per 7-8 l have been transported in these containers.

After capture by drift-net or trawl on research vessels the fish have been transported to the aquarium port in a canvas tank holding about 700 l with a continuous circulation of water:

INITIAL ESTABLISHMENT IN THE AQUARIUM

Initial establishment of the herring is the next stage. There are two obstacles to be overcome, one to prevent the initial mortality of the fish and the other to induce feeding. The criterion of successful establishment is whether the fish start feeding or not. Before detailing the factors involved, a description will be given of the aquarium facilities.

AQUARIUM FACILITIES

Three tanks, all of reinforced concrete (see Fig. 1 and Plate I) are used for most of the work on herring. Two of these tanks are the same size measuring $3.7 \times 1.8 \times 1.1$ m and containing about 7500 l of water. The third was specially designed for behaviour studies and consists of two tanks each measuring $2.2 \times 1.6 \times 1.1$ m containing about 4000 l of water joined by a channel 3 m long and 0.7 m wide. The effective cross section of this channel can be varied by using partitions with different sized apertures between them. In addition watertight doors can be fitted into slots at each end of the channel. The tanks are all covered by a ridged roof with hinged traps. The walls of the behaviour tank are painted with a bitumen-based grey emulsion paint while those of the other two tanks are untreated. One of the tanks is fitted with white corner baffles made of stainless steel. (Tester (1952) found a system of baffles to be beneficial when establishing tuna in aquaria). The behaviour tank was designed with the corners covered in and white plastic sheets can be fitted into grooves in order to cover the corners.

The water in all three tanks is circulated through a closed system (i.e. the water is not being replaced) which incorporates a filter. The water is raised by an "air-lift" system to the filter where it seeps through a filter bed of sand, gravel, marble and granite chips and back into the tanks. The total volume of water in the tanks is passed through the filter about once every nine hours.

In addition trays of mussels (*Mytilus edulis*) are kept in the tanks. The filter-feeding activity of these animals helps to reduce the flora and improves the clarity of the water. Despite this, cycles of plankton blooms have been noticed and are difficult to suppress. They do not seem to harm the herring but cloud the water and so make observations difficult.

The tanks are occasionally drained and refilled after removing the fish but usually the water is only reduced as far as possible without removing the fish and the tanks "topped up" with fresh sea water.

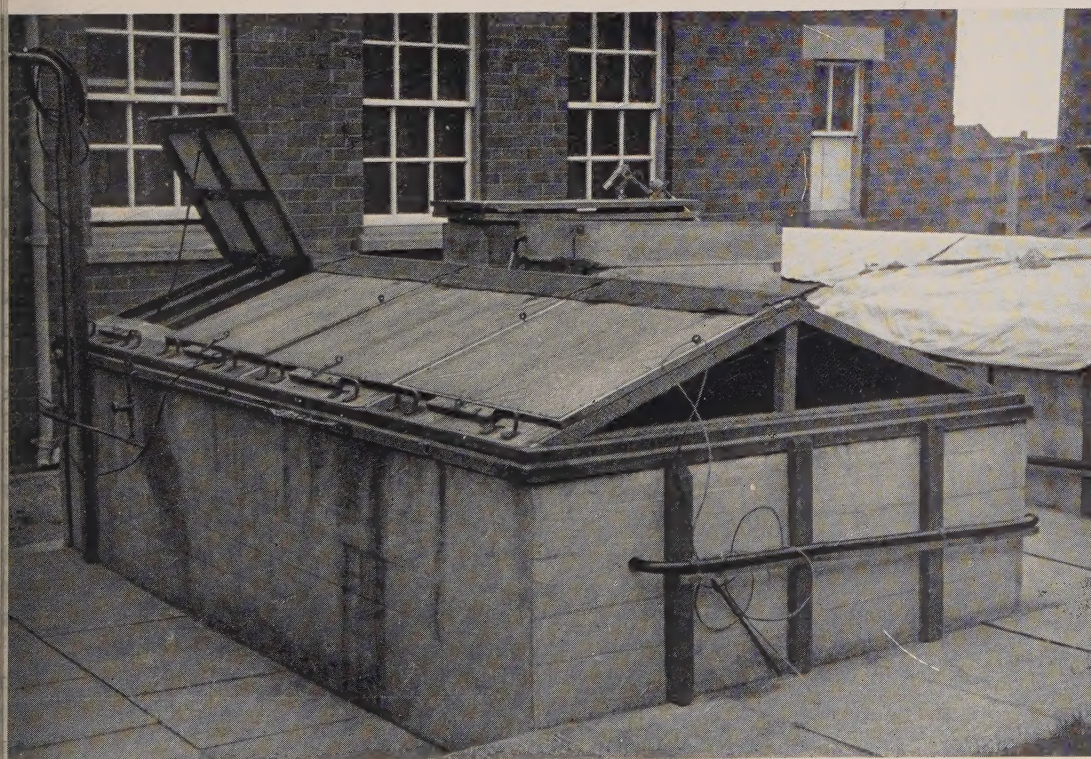


Plate 1. A. View of all tanks from the east ("behaviour tank" nearest).
 B. View from the south of one of the larger tanks.

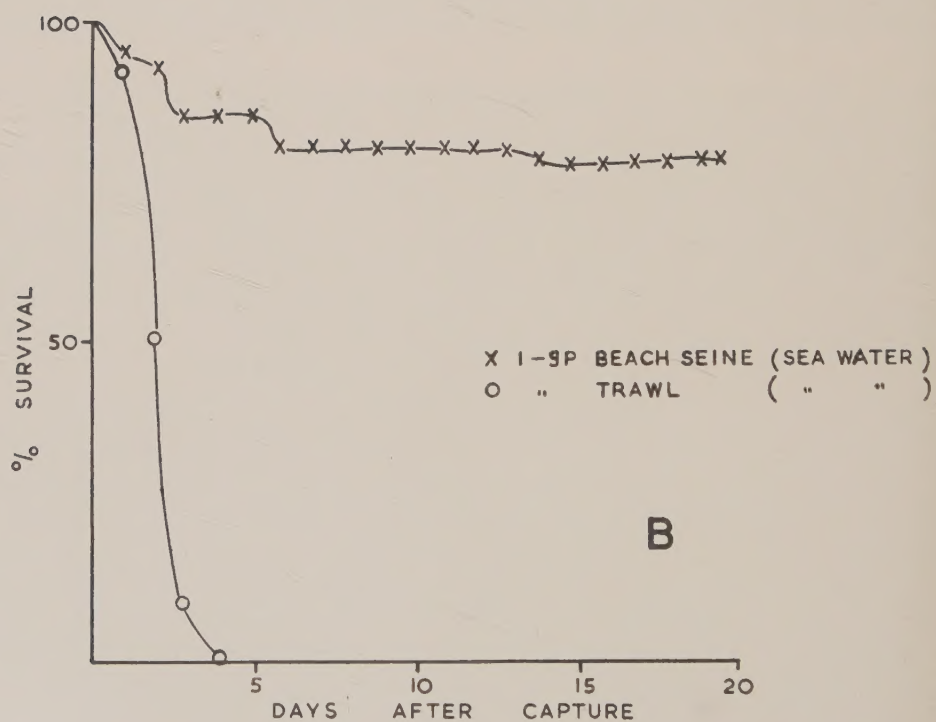
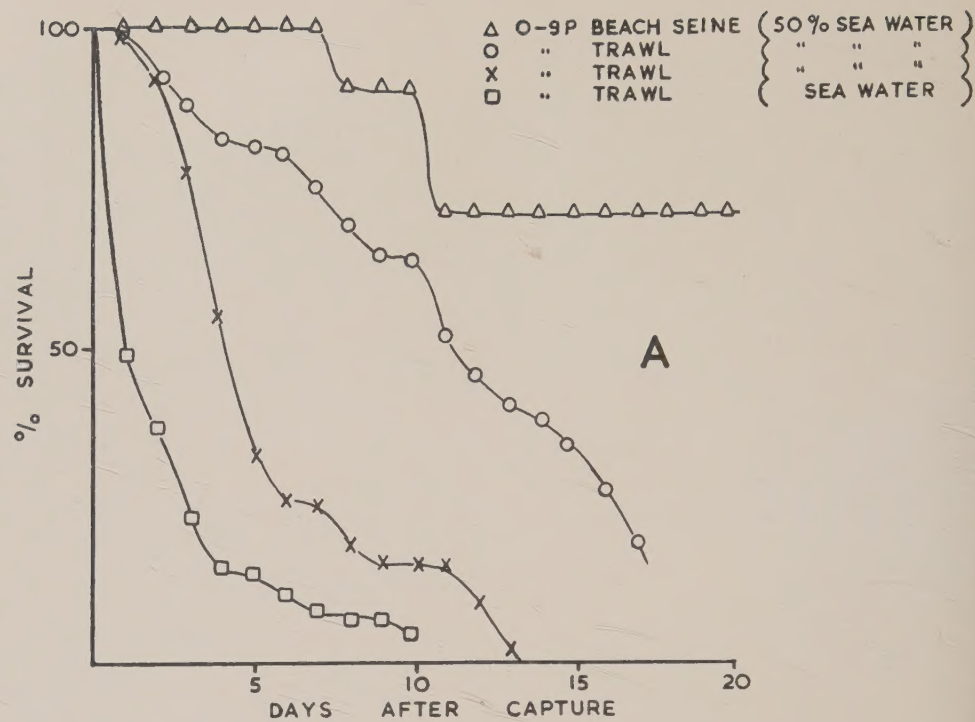


Fig. 2 A. Mortality of 0-group herring after capture under different conditions.
 B. Mortality of 1-group herring after capture by trawl and beach seine.

eaten food is continually being siphoned off, the level gradually drops and the tanks require a "topping up" about once every six weeks. When the tanks are partially or totally drained samples of old water are taken for salinity, oxygen and phosphate determination. Samples of the water have been cultured for the identification of micro-organisms. The dominant one, a naviculoid diatom, was found in large numbers and was of a type flourishing at low light intensities in water containing much organic matter and nutrients. The phosphate value in one tank, for instance, was $6.3 \mu \text{g-At PO}_4\text{-P/l}$ (ten times that in offshore sea water) when it became necessary to change the water.

The only natural light to enter the tanks was through the open gable ends. However, various types of artificial light were used. A 15 watt green bulb was suspended over the centre of the tank when fish were first introduced. Later a 15 watt clear bulb was used which gave adequate light for feeding the fish. In some experiments a single bar of 80 watt fluorescent daylight lighting, five feet long, was used with a reflector. This gave a light of about 700 metre candles above the surface immediately below the bar and about 80 m.c at the surface around the edges of the tank. The lights could be controlled with a switch.

It was not easy to control the temperature of the water during extremes of weather. Thermostatically controlled heaters kept the water at about 11°C most of the year, but no cooling plant was available, so during the summer the temperature sometimes rose to 16°C , while during the winter the temperature fell to 0.5°C when no heater was used. After some difficulty in finding suitable heaters, special immersion heaters 1 kW elements were fitted into iron tubes and later commercially produced silica tubes containing 2 kW heating elements were obtained. These maintained a temperature of 11°C even in severe conditions.

Other tanks, in the main laboratory aquarium, have also been used. These are supplied from a large reservoir with a continuous flow of sea water which is filtered and returned to the reservoir. Two different types of tanks have been used, the first of teak with a glass front holding about 750 l, the second of iron with a glass front holding about 3,000 l. A 450 l tank made of teak and glass with a closed circulation system has also been used.

L. MORTALITY

On arrival at the laboratory the herring are transferred to the tanks immediately and no attempt is made to weigh, measure or take scale samples from them. On one occasion only some fish were tagged and only a few were put into the tanks.

Originally it was thought that the corner baffles and a continuous source of light were beneficial in helping the fish to orientate themselves to the tank. However, fish have been established without these. A low temperature (about 6°C) seems to be an advantage in that it reduces the activity of the fish. A variable mortality occurs after placing the fish in the tanks. Post mortems are carried out on all fish, which are weighed, measured and examined for external damage, abrasion of the fins, parasites, external blood spots, damage to the jaw and operculum and for the condition and colour of the gills. The body cavity is examined for lesions, swelling of the swim bladder, colour of the liver and spleen, fat deposits, gut contents and for sex and maturity. Later certain parts of the body, mainly the head and pituitary, are removed for histological examination and in some cases blood samples are taken for freezing point determinations.

The behaviour of moribund herring suggests that the sense of equilibrium is impaired. The post mortems show that the most obvious cause of death is epidermal damage and removal of scales. It was considered that this possibly upsets the water balance of the fish, and the resulting change in osmotic pressure of the blood affects the brain and, in particular, the centres of equilibrium control. In order to test this a tank was set up containing diluted sea water (salinity 17‰), which is about isotonic with the blood of herring. While this apparently reduced the initial mortality (see Fig. 2), which is therefore probably caused by an osmotic upset, it did not overcome the later mortality, the cause of which is unknown. The most striking effect of reduced salinity was on moribund fish. In normal sea water they remain moribund for only a few hours; in a salinity of 17‰ they sometimes remained moribund for as long as seven days. It is of interest to note that Brock and Takata (1955) used diluted sea water to increase the survival of bait fish in the tuna fishery at Hawaii.

Some other examples of the mortalities experienced under different conditions are also shown in Fig. 2. Three comparisons can be made. Firstly the lower graph shows the superiority of the seine over the trawl for capturing 1-group herring. Although not shown in Fig. 2, no fish caught in a beach net were ever established. The upper graph, for 0-group fish, shows (1) how beach seining is again superior to trawling, (2) how the initial mortality is reduced by using diluted sea water, and (3) how variable the results may be, even with one method of capture. It should be noted, however, that diluted sea water (17‰) does not seem to reduce the later mortality of trawl caught fish. The increased mortality of non-feeding 0-group fish, found on occasions about two weeks after capture and shown in Fig. 2, is thought to be due to starvation. Fat analysis on a sample of such dead fish showed that the total oil content was 1.84% of the wet weight, which is a very low figure.

INITIATION OF FEEDING

Once the initial mortality is overcome the fish must be induced to feed. About two days after capture the fish are offered food (mainly chopped *Mytilus* or *Loligo*) at least once per day. Details of the capture and feeding procedures are given in Blaxter and Holliday (1958). Whether feeding starts or not depends on a number of circumstances such as the size of tank, the temperature and whether feeding herring are already present. It may also be an advantage to have quite a large number of fish present (over 50) as one or two may start feeding and induce feeding in the other fish. If the fish are going to start feeding and become established this usually occurs within the first two weeks.

The use of tanks of adequate size is probably one of the most important factors in deciding whether the fish will start feeding or not. Previous workers (see table in appendix) have used tanks ranging from 100–450,000 l. While herring may survive for a time in quite small tanks, published work shows that they will not be maintained or feed unless the tank is above a certain size, i.e. over about 500 l for 0-group fish and over about 1000 l for 1-group fish. Larger tanks than these might be even better. It is interesting to note that the only instance of herring maturing in captivity so far published, was in a tank of 450,000 l. The results of using the different tanks in our experiments are shown in Table I. They show that the minimum tank size for 0-group fish to feed appears to lie between 450 and 750 l. For 1-group fish it is between 3000 and 7500 l. It is important to note that the fish matured in a 7500 l tank.

TABLE I

Size of tank (litres)	Material	Reaction of 0-group fish 5–15 cm	Reaction of 1-group fish 15–20 cm
450	teak and glass	no feeding initiated	no feeding initiated
750	teak and glass	feeding initiated	no feeding initiated
3000	concrete and glass	feeding initiated	no feeding initiated
7500	concrete	feeding initiated	feeding initiated

Fish were not induced to feed in tanks below a temperature of about 10°C. The presence of a large number of fish is a great asset in initiating feeding; see Blaxter and Holliday (1958).

In the light of our results the following recommendations may be made for establishing herring in aquaria:

- (1) Capture should be rapid and cause a minimum of even superficial damage. Thus a beach seine or hand net seems to be most suitable.
- (2) Transport should be in vessels with smooth walls of adequate size (i.e. one fish 5–15 cm long per 2–3 l or one fish 15–25 cm long per 7–8 l). Under these conditions there would be an adequate oxygen supply for short journeys. On longer ones (of an hour or more) the water should be oxygenated.

The fish should be placed in tanks which are as large as possible, at least 750 l for fish up to 15 cm long and if possible over 3000 l for larger fish. A cylindrical tank might be advantageous. An adequate depth for the tanks is about one metre. It seems beneficial to have a fairly low temperature when transferring the fish to the tanks. For initiating feeding a temperature of 10–12°C is desirable and chopped *Mytilus* and *Loligo* are useful foods. The use of isotonic sea water reduces the initial mortality.

MAINTENANCE AND FEEDING AFTER ESTABLISHMENT

After feeding has been initiated a general feeding routine is carried out. This and the effect of such factors as light, temperature and noise on feeding are described in Blaxter and Holliday (1958), which also includes an analysis of growth rate and the factors affecting selection of food and palatability. The fish are fed four times per day and recordings of temperature, light intensity, weight of food eaten and duration of feeding activity made. Many of the fish showed signs of growth with increases in weight of 10 g and in length of 2–3 cm in the 1-group fish during a period of nine months. Some larger fish matured and reached stage VI (ripe) but so far there have been no signs of spawning. Some fish 20 cm long have been kept for over two years.

It is considered that the fish should be handled as little as possible. They may however be transferred from one tank to another by a shallow fine mesh net with a wide mouth. This often results in little breaking activity. Some difficulty may be experienced in catching the fish. However a sheet of netting made which can be placed at one end of the tank and gradually moved up to the other end, the fish being thus confined in a smaller space, which facilitates capture. For identification the fish have been marked in various ways. In some cases hydrostatic tags have been used, attached through the dorsal fin. In others the caudal fin has been clipped.

Various methods of weighing are used. Initially fish were placed in a sling of wet muslin attached to a spring balance. Later a perspex box 25 × 5 × 12 cm, fitted with a sliding lid and filled with water, was used on a scale pan. Anaesthetics have also been employed, the fish being weighed as quickly as possible on an accurate balance while under anaesthesia. Urethane (1% solution) was not found to be satisfactory and the herring took a long time to recover. Tricaine methane sulphonate (metacaine) has been used with great success, a solution of 20 p.p.m. being adequate. This anaesthetic has also been used in various surgical techniques, incorporated in a supply of running sea water passed through the gills during an operation. It is considered that a more extensive use of anaesthetics when handling fish may result in a much reduced mortality.

When the fish have started feeding only occasional deaths occur. When they do, however, it is usually difficult to find the cause of death, the fish often having adequate fat reserves. The only signs of any specific disease which have been encountered was of fin rot in 0-group fish. This has been treated successfully with phenoxethol and by feeding with terramycin. Phenoxethol has been painted directly on the affected part and the treatment appears to have been effective. Terramycin has been used at a level of 1.5 mg/g fish/day (see Farrin *et al.*) and later at a much reduced level (0.1 mg/g fish/day) and seems to be effective. The antibiotic is fed to the fish incorporated in 15% gelatine made up with concentrated squid extract. The fish accept this readily. Terramycin proved valuable as a prophylactic for not cured previously infected fish.

SUMMARY

The factors involved in establishing herring in aquaria are considered in three stages.

1. Capture. Greatest success has been obtained using a beach seine for catching the fish.
2. Transport. The fish are transported in small numbers in carboys or bins.
3. Initial establishment in the aquarium. Details of the aquarium facilities are given. The fish kept mainly in 7500 l concrete tanks with a closed water circulation. The initial mortality of herring after capture is considered. Low temperatures and sea water isotonic with the blood found to reduce the initial mortality. Feeding is usually initiated in water of 11–12°C with chopped *Mytilus* or *Loligo* as food.
4. Maintenance and feeding after establishment. Some details are given of feeding procedure, methods of catching and moving fish once established, weighing, anaesthetics and treatment of disease.

REFERENCES

- ANON. 1952. Progr. Rep. Calif. Sardine Res. 1st Jan. 1951–30th June 1952, p. 22.
- BATTLE, H. I., HUNTSMAN, A. G., JEFFERS, ANNE M., JEFFERS, G. W., JOHNSON, W. H. and MCNAIRN, 1936. 'Fatness, digestion and food of Passamaquoddy young herring.' J. biol. Bd Can., 2, 401–429.
- BLAXTER, J. H. S. and HOLLIDAY, F. G. T. 1958. 'Herring (*Clupea harengus* L.) in aquaria. II. Feeding.' Res. Scot., 1958 No. 6.
- BROCK, V. E. and TAKATA, M. 1955. 'Contributions to the problems of bait fish capture and mortality.' Indust. Res. Advis. Coun. Grant No. 49. (Hawaii).
- BÜCKMANN, A., HARDER, W. and HEMPEL, G. 1953. 'Unsere Beobachtungen am Hering, *Clupea harengus* L.' Kurz. Mitt. Inst. Fischereibiologie Hamburg, 3, 22–42.
- COWAN, D. 1938. 'Tank life of fish in the aquarium of the Dove Marine Laboratory, Cullercoats.' Rep. Mar. Lab., 3rd series (5), 36–39.
- FARRIN, A. E., SCATTERGOOD, L. W. and SINDERMAN, C. J. 1957. 'Maintenance of immature sea herring in captivity.' Prog. Fish. Cult., 19, 188–9.
- JOHNSON, W. H. 1939. 'Feeding of the herring.' J. Fish. Res. Bd Can., 4, 392–5.
- LOUKASHKIN, A. S. and GROODY, T. C. 1955. 'On the Pacific sardine (*Sardinops caerulea* Girard) in aquaria: transportation, handling, maintenance and survival.' Proc. Calif. Acad. Sci., 28, 339–353.
- OUTRAM, D. N. 1951. 'Observations on the retention and spawning of the Pacific herring.' Progr. Rep. Stas. Nanaimo and Prince Rupert, No. 87, 32.
- SCHÄFER, W. 1955. 'Über das Verhalten von Jungheringsschwärmen im Aquarium.' Arch. Fischw., 276–287.
- SHELFORD, V. E. and POWERS, E. B. 1915. 'An experimental study of the movements of herring and other marine fish.' Biol. Bull. Woods Hole, 28, 315.
- SKOGLUND, G. 1953. 'Skrammer ekolod fisken.' Ostkusten, 25 (6), 14.
- TESTER, A. L. 1952. 'Establishing tuna and other pelagic fish in ponds and tanks.' Spec. sci. Rep. Fish. Wildl. Serv., no. 71.
- VERHEIJEN, F. J. 1953. 'Laboratory experiments with the herring *Clupea harengus*.' Experientia, 9, 193.
- 1956. 'On a method for collecting and keeping Clupeoids. . . . ' Pubbl. Staz. zool. Napoli, 28, 225–230.

APPENDIX

Fish	Author	Size of fish (cm)	Size of tank (litres)	Temperature range (°C)	Means of Capture	Means of transport	Experiments carried out	Time kept
<i>Tupea urengus</i>	Battle <i>et al</i> (1936)	9-20	900	0.75-14.5	Seine from weirs	Galvanised iron tub	Food preference rates of digestion, optimum light conditions	Some months
"	Cowan (1938)	2.9-5.2	—	—	Taken from a rock pool	—	—	8 years
"	Johnson (1939)	14-18	112-1500	3.8-15.0	—	—	Effect of temperature and light on feeding	—
"	Bückmann Harder and Hempel (1953)	<1-12	5-2800	—	—	—	Effect of light, currents, salinity barriers, feeding behaviour	—
"	Skoglund (1953)	25-30	1100	—	—	—	Effect of echosounders	—
"	Verheijen (1953)	2-12	500-2000	—	From palisades near the shore	60 l containers	Effect of sounds light and obstacles	—
"	Schäfer (1955)	4-17	1700-43,000	—	Sink net	—	Shoaling behaviour	—
"	Farrin <i>et al</i> (1957)	5-20	550-7500	1-18	Seine net	45 l containers	Study of feeding and mortality	2 years
<i>Tupea flasi</i>	Shelford and Powers (1915)	6	24	—	—	—	Reaction to temperature, salinity and oxygen gradients, resistance to CO ₂ and H ₂ S	—
"	Outram (1951)	Adult	450,000	—	—	—	Growth and spawning	Some months
<i>Tupea hardus</i>	Verheijen (1956)	10	—	—	Attracted to surface by lights	60 l containers	—	—
<i>Linops rulea</i>	Anon (1952)	Adult	—	10-12	—	—	Schooling pattern, stimuli involved in feeding, effects of electric fields	—
"	Loukashkin and Groody (1955)	Adult	4500	11-20.5	—	450 l containers with lights	A study of feeding mortality, general maintenance	Nearly 3 years

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